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How to cite:

Alam, Atm S.; Dooley, Laurence S. and Poulton, Adrian S. (2012). Energy Efficient Relay-Assisted Cellular Network Model using Base Station Switching. In: IEEE Global Telecommunications (GLOBECOM 2012): 2nd International Workshop on Multicell Cooperation, 3-7 Dec 2012, Anaheim (California), USA.

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Version: Accepted Manuscript

Link(s) to article on publisher's website:

<http://dx.doi.org/doi:10.1109/glocomw.2012.6477742>

<http://www.ieee-globecom.org/wcp.html>

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Energy Efficient Relay-Assisted Cellular Network Model using Base Station Switching

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Abstract—Cellular network planning strategies have tended to focus on peak traffic scenarios rather than energy efficiency. By exploiting the dynamic nature of traffic load profiles, the prospect for greener communications in cellular access networks is evolving. For example, powering down *base stations* (BS) and applying cell zooming can significantly reduce energy consumption, with the overriding design priority still being to uphold a minimum *quality of service* (QoS). Switching off cells completely can lead to both coverage holes and performance degradation in terms of increased outage probability, greater transmit power dissipation in the up and downlinks, and complex interference management, even at low traffic loads. In this paper, a cellular network model is presented where certain BS rather than being turned off, are switched to low-powered *relay stations* (RS) during zero-to-medium traffic periods. Neighbouring BS still retain all the baseband signal processing and transmit signals to corresponding RS via backhaul connections, under the assumption that the RS covers the whole cell. Experimental results demonstrate the efficacy of this new *BS-RS Switching* technique from both an energy saving and QoS perspective, in the up and downlinks.

I. INTRODUCTION

Despite cellular networks being one of the most fertile wireless communication areas, major concerns persist about future spectrum shortages and critical energy consumption issues due to its inexorable growth, which has far exceeded expectations¹. The rise in wireless network energy consumption is reflected by increasing greenhouse gas emissions, which has been recognised as a serious threat to both environmental protection and sustainable development. Vodafone's statistical results, for example, show the total energy consumption has reached 4,117 GWh in the 2010/11 base year, which equates to 2.29 millions of tonnes gross CO_2 emissions, with 61% of this being generated by *base stations* (BS) [1]. The outcome is that not only is this rapid growth in wireless networks impacting upon the economy, but also on the environment. Strategies have been proposed by mobile operators to sustain capacity growth without environmental impact, by designing green communication networks with reduced operational energy consumption together with limits upon energy bills. The European Commission has already acted seeking a 20% cut in CO_2 emissions allied with a 20% improvement in energy efficiency by 2020 [2]. Analogously, some UK mobile phone

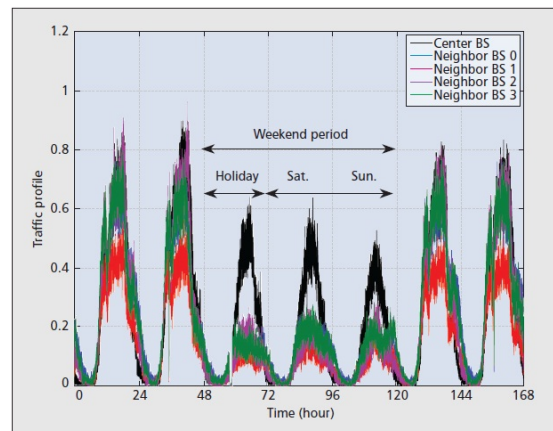


Fig. 1. Normalised traffic variations in both time and spatial domains across a one-week period [3].

operators including Vodafone and Orange have announced CO_2 emission reductions in the range 20% to 50% by 2020 [1].

In current cellular networks, both the cell size and capacity are fixed based on the peak traffic loads for every cell, irrespective of either the time of day or traffic profile. Fig. 1 shows a typical load profile [3] across one week, which clearly exhibits significant spatial and temporal fluctuations. The corollary is that during either low or no traffic periods i.e., early mornings or daytime in residential areas, when loads are small, many BS are underutilized, but still consume significant amounts of energy. Various techniques have been proposed [4]–[9] to reduce energy consumption in network operations by either powering down or putting the BS to sleep during low traffic periods. While such dynamic schemes regulate the energy efficiency by switching the BS on/off depending on network traffic variations, sustaining service provision to those cells which have been switched off raises major design challenges. For example, ensuring regulatory constraints are upheld, protecting spatial coverage, interference management, and the inevitable increasing power consumption to service *mobile stations* (MS) in off-cells. The approach adopted in [5] and [6] achieves BS energy savings by switching certain macrocells off and then applying cell zooming, so deploying more but smaller cells. A shortcoming of increased cell deployments in a particular area is it can lead

¹Gartner Inc. Research, 2011.

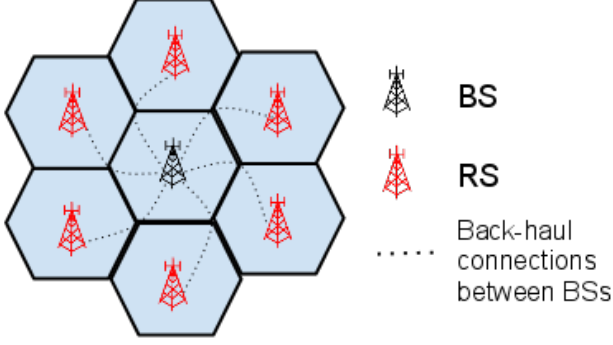


Fig. 2. Example cell layout showing the *base station* (BS) and *relay station* (RS) arrangement for the *BS-RS Switching* model.

to a higher handover frequency and occurrences of the ping-pong effect [8] due to greater incidences of BS switching. This incurs higher signalling overheads and ultimately compromises the overall service delivery.

This paper investigates dynamic traffic-aware BS switching modes, where the BS can alter its operating modes between standard BS operations and switching to *relay station* (RS) mode, the so-called *BS-RS Switching* model. Depending on the traffic fluctuations, load profiles are divided into two categories; i) *Zero-to-medium traffic period* - when a BS switches to the RS mode and turns off all its high-power consuming equipment; and ii) *Peak traffic period* - when all BS are fully active. The rationale for switching from a BS to RS mode is to ensure those MS that would be served by the switched off cell and may suffer deep fading, are still be able to receive the same QoS. Furthermore, since the propagation distance has been shortened between the MS and serving BS via the backhaul connection, the required MS transmit power is concomitantly reduced compared with the BS sleep and cell zooming technique [5]-[6].

The remainder of the paper is organized as follows. In Section II, the *BS-RS Switching* model is formally introduced. In addition, both the propagation loss and power consumption models are considered together with the supporting outage probability theory. Section III provides an analysis of the energy saving simulation results using the proposed energy minimisation strategy for both the *uplink* (UL) and *downlink* (DL), while Section IV provides some concluding comments.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. System Model

The network scenario shown in Fig. 2 is assumed for this analysis. It consists of seven arbitrary hexagonal shaped cells without sectoring. The centre BS is kept switched on all the time, with the other BS having the capability to switch to a relay (RS) mode depending on their traffic conditions. Each BS is located at the centre of a cell and possesses an omnidirectional antenna. Every cell also has an amplify-and-forward RS at the same position with the equal coverage capability as

the BS. In this arrangement, both the BS and RS use a common antenna. The user arrival rate for BS_m at time t is modelled as a Poisson process with mean arrival rate $\lambda_m(t)$ [users/sec], under the assumption that the service time h [sec/user] is constant. The traffic profile of BS_m is $\rho_m(t) = \lambda_m(t) \cdot h$, which is varied as a function of time over a 24-hour period. Users are randomly located in each cell according to a normal distribution.

The two load profile categories defined above will now be considered in respect of the proposed *BS-RS Switching* cellular network model:

Case I: Zero-to-medium traffic period: During this period, certain BS will be switched off to conserve energy, while low-powered RS are alternatively used to cover the area of switched off cell. BS_m can be switched to RS mode provided neighbouring active BS are able to handle all the MS served by BS_m . The approximate handover traffic $\bar{\rho}(t_m^{off})$ of this BS is distributed among the neighbouring active BS according to their own traffic profile, i.e., traffic loads $\rho'_1(t_m^{off}), \rho'_2(t_m^{off}), \dots, \rho'_{M_m}(t_m^{off})$ are distributed to the 1st, 2nd, \dots , M_m^{th} neighbouring active BS, respectively. For simplicity, the handover traffic is assumed to be equally distributed amongst the neighbouring active BS for homogeneous traffic conditions, so the handover traffic of each neighbouring active BS is approximated as:

$$\rho'_1(t_m^{off}) = \rho'_2(t_m^{off}) \dots = \rho'_{M_m}(t_m^{off}) = \bar{\rho}(t_m^{off})/M_m$$

The new cell traffic load for each of the neighbouring active BS when BS_m is switched to RS mode at t_m^{off} is then:

$$\bar{\rho}_n(t_m^{off}) = \bar{\rho}(t_m^{off}) \cdot \left(1 + \frac{1}{|M_m|}\right); \quad n \in M_m \quad (1)$$

So when BS_m is switched to RS mode at time t , the following two conditions must be satisfied [3]:

$$\bar{\rho}_n(t) = \bar{\rho}(t) \cdot \left(1 + \frac{1}{|M_m|}\right) < \rho_{max}; \quad \forall n \in M_m \quad (2)$$

and

$$\bar{\rho}_m(t) < \rho_{th} \quad (3)$$

where ρ_{max} is the maximum traffic load that the neighbouring active BS_n for $n = 1, 2, \dots, M_m$ is able to handle and ρ_{th} is the switching threshold.

When switching from a RS mode back to the BS mode, the corresponding traffic profile condition to be upheld is:

$$\bar{\rho}_m(t) \geq \rho_{th} \quad (4)$$

Case II: High traffic period: In this scenario, all BS actively provide services, with some likely to be more crowded than others. While a BS with a low traffic load is able to serve MS in a neighbouring cell which may have a high traffic load, by increasing its transmit power to reduce the blocking probability in the crowded cell [8], this particular situation is not considered in this paper.

A number of benefits ensue from adopting the new *BS-RS Switching* model compared to the traditional BS sleep approach [5]- [6]. These include:

- i) minimising the average energy consumption in both the DL (BS) and UL (MS) in the *Case I* scenario;
- ii) maintaining the same coverage and QoS;
- iii) Lower outage probability compared with [5] and [6].

B. Propagation Channel Model

This paper uses a modified IEEE 802.16j channel model based on the log-normal shadowing path-loss paradigm with the Type B (LOS/NLOS) intermediate path-loss condition being employed for the links between the BS-MS/RS-MS [10]. All the various system parameters and their values are provided in the TABLE I. It is assumed *inter-cell interference* (ICI) is effectively managed in accordance with accepted interference averaging and management techniques [11]. The path-loss equation relating to the modified IEEE 802.16j channel is given by [10]:

$$L(d) = \begin{cases} 20 \log \left(\frac{4\pi d}{\lambda} \right) & \text{for } d \leq d'_0 \\ A + 10\delta \log \left(\frac{d}{d'_0} \right) + C_f + C_h & \text{for } d > d'_0 \end{cases} \quad (5)$$

where,

d = distance between BS/RS and MS,

λ = wavelength,

$\delta = a - bh_{TX} + c/h_{TX}$,

h_{TX} = transmit antenna height,

d_0 = reference distance (100m),

a , b , and c are the model parameters defined in TABLE I,

and A , C_f , C_h and d'_0 are functions of the wavelength, antenna heights and reference distance respectively, as given in [10].

By considering a log-normal distributed shadowing (LogF) effect with zero mean and a standard deviation σ i.e., $\text{LogF} \sim (0, \sigma^2)$, the corresponding path-loss PL is given by [10]:

$$PL(d) = L(d) + \text{LogF} \quad (6)$$

C. Power Consumption Model

A typical cellular network comprises three main elements: the core network, BS and MS. The BS consumes by far the most energy, as it includes operational units such as power amplifiers, baseband units, feeder networks and site cooling systems. The relationship between the average total power consumption and the average radiated BS power can be modelled as [4]:

$$P_{T,DL} = a_m \cdot P_t + P_f \quad (7)$$

where $P_{T,DL}$ and P_t respectively denote the average total consumed and transmission power in the DL, while a_m is a power scaling factor which reflects both amplifier and feeder losses. P_f models the fixed power components which are independent of the transmit power. This includes all electronic circuit power dissipation due to site cooling, signal processing hardware and battery backup systems. Both the power model parameters (a_m and P_f) are also dependent upon the operating mode i.e., either BS or RS modes, where $a_{m,BS} > a_{m,RS}$ and $P_{f,BS} > P_{f,RS}$ [12].

From a MS power consumption perspective, the main constituent is transmission power, which increases with the distance between the MS and BS due to path-losses and shadowing. The total MS power consumption can thus be expressed as:

$$P_{T,UL} = \sum_{i=1}^M P_{t,i} = \sum_{i=1}^M P_{r,th} \cdot 10^{PL(d_i)/10} \quad (8)$$

where $P_{t,i}$ is the transmission power of the i^{th} MS for $i = 1, 2, \dots, M$. $P_{r,th}$ is the minimum threshold received power to ensure a minimum QoS and $PL(d_i)$ is the propagation path-loss at distance d_i which includes shadowing effects.

D. Outage Probability Analysis

The energy-saving performance of the proposed *BS-RS Switching* model is analysed under certain outage probability constraints. Outage can occur for two reasons [13]: i) the received signal strength is less than a predefined signal strength threshold, γ ; and/or ii) there is no available service channel. Since the switching operation is only performed during *zero-to-medium* traffic loads, limited service channel availability is a highly improbable cause of outage in the *BS-RS Switching* technique. Let $\Psi(d_i)$ denote the outage probability at the i^{th} MS, with a distance d_i between MS and the served BS or RS, and $\gamma = P_{r,th}$. The signal strength outage probability at distance is then:

$$\begin{aligned} \Psi(d_i) &= Pr(P_{r,i} \leq \gamma) \\ &= \Phi \left(\frac{10}{\sigma} \log_{10} \left(\frac{\gamma}{P_{t,i} \cdot 10^{-L(d_i/10)}} \right) \right) \end{aligned} \quad (9)$$

where $P_{t,i}$ and $P_{r,i}$ are respectively the transmitted and received signal powers of the i^{th} MS at distance d_i , and $\Phi(*)$ is the *cumulative distribution function* (CDF) of standard normal distribution.

E. Problem Formulation

Given the cell scenario in Fig. 2, it is assumed there are N available channels in every cell for transmission, with each having a different channel gain and bandwidth $W = B/N$, where B is the cell bandwidth. For simplicity, it is also assumed that different frequency bands are used by adjacent BS so ICI can be ignored. If $P_{t,min}$ is the minimum channel transmission power which guarantees a prescribed minimum data rate r_{min} for a user, then it must satisfy the following:

$$r_{min} = W \log_2 \left(1 + \frac{\eta_0 P_{t,min}}{d^\alpha} \right) \quad (10)$$

so:

$$P_{t,min} = \frac{(2^{r_{min}/W} - 1) d^\alpha}{\eta_0} \quad (11)$$

where α is the path-loss exponent; $\eta_0 = \frac{G_0}{N_0}$ includes the effect of the antenna gain G_0 and thermal noise N_0 , and d is the distance from the BS to the MS.

Equation (11) reveals the transmit power depends on the distance between the BS and MS, so to achieve a given minimum

data rate, the aim must be to maintain a minimum distance between the transmitter and receiver to reduce propagation attenuation. In the *BS-RS Switching* model, since the RS is deployed at the same position as the BS, the distance between a BS and MS will be the same when the BS is switched to RS mode, whereas in other models [5]–[9] [12] [13], this distance can be significant.

In addition, the overall cell throughput can be derived from:

$$R = B \sum_{i=1}^N \log_2 \left(1 + \frac{\eta_0 P_{t,i}}{d_i^\alpha} \right) \quad (12)$$

Based on (12) and the total BS power consumption, the *energy efficiency* (EE) of a cell in *bits per joule* [14] is:

$$\eta_{EE} = \frac{R}{P_T} = \frac{B \sum_{i=1}^N \log_2 \left(1 + \frac{\eta_0 P_{t,i}}{d_i^\alpha} \right)}{a_m \cdot P_t + P_f} \quad (13)$$

where P_T and $P_{t,i}$ are the total power consumption in the DL and i^{th} channel transmission power respectively. To attain a high EE while concurrently guaranteeing the QoS for each user, the objective is to turn off certain BS and switch to low-powered RS mode during *zero-to-medium* traffic periods. *BS-RS Switching* decisions are based upon whether the traffic load is less than a prescribed threshold within a cell over a particular time interval, so the design problem can thus be accordingly formulated as:

$$\max_{A_m} \quad \eta_{EE} \quad (14)$$

s. t. same $\Psi(d_i)$, R and coverage as that when all BS are active,

$$\sum_{i=1}^N P_{t,i} = P_t \leq P_{max},$$

$$W \log_2 \left(1 + \frac{\eta_0 P_{t,i}}{d_i^\alpha} \right) \geq r_{min}, \quad \forall i,$$

$$\text{and } A_m(x) \in \{0, 1\}, \forall x \in \{t, t+1\},$$

where P_t and P_{max} are respectively the total and maximum transmission powers of a particular BS. $A_m(t)$ is the mode switching activity function for BS_m . *BS-RS Switching* depends upon the traffic load at time t and this is performed on an hourly basis throughout the day with the satisfaction of eq. (2) & (3), i.e. $\forall \rho(t) < \rho_{th}$ for $t = 1, 2, \dots, 24$, where ρ is the vector of all traffic loads in each cell during one day, and ρ_{th} is the threshold traffic load required to switch the operation mode (either BS-RS or RS-BS). The objective function in (14) is numerically solved using an exhaustive search algorithm. The minimum energy consumption performance of both the *BS-RS Switching* model and BS sleep mode technique [5]–[6] will now be investigated.

TABLE I
SIMULATION ENVIRONMENT PARAMETERS

Parameters	Value
Carrier frequency	2 GHz
Cell radius	500m
Cell sectoring	No
BS max transmit power	43dBm
BS-to-BS distance	>1km
RS coverage radius	500m (equal to cell radius)
BS/RS antenna gain	16dBi
BS/RS antenna height	32m
Noise power	-141dBm/Hz
Channel model	
BS-MS/RS-MS link	Type B(suburban, terrain Type B)
Path-loss model	(IEEE 802.16j): Type B; eq. (5)
Channel model constants used in (5)	a b c
	4 0.0065 17.1
Receiver sensitivity	-99dBm (MS), -103dBm (BS)

III. SIMULATION AND RESULTS ANALYSIS

To assess the energy efficiency performance of the proposed *BS-RS Switching* model, both the BS and MS perspectives were analysed, in a test environment developed using Matlab. TABLE I details all the simulation environment parameters, which were chosen to be congruent with the 3GPP LTE specifications [15], with hexagonally shaped macrocells considered. The values of $a_{m,BS}$, $a_{m,RS}$, $P_{f,BS}$ and $P_{f,RS}$ were respectively preset to 21.45, 7.84, 354.44W and 71.5W, as in [4] and [14]. Hourly time intervals were used in the analysis as in [16], with the traffic arrival process in each interval assumed to be Poisson and users located in each cell according to a normal distribution. For EE measurements, the bandwidth of each cell was 5MHz and the MS bit-rate requirement 90kbps. The various hourly interval results for both *BS-RS Switching* and the BS sleep [5]–[6] techniques were then averaged and compared across an entire day.

Four hourly snapshots of the energy consumption in each cell during different traffic conditions are shown with *cell activation pointers* (CAP) in Fig. 3. The CAP '1' nomenclature refers to when the BS is active i.e., $A_m(t) = 1$ for BS_m at time t while the '0' means the corresponding BS is switched to RS mode i.e. $A_m(t) = 0$. The plots clearly reveal the improved energy consumption of each cell compared with no switching. For example, in the 20th hour graph, three BS can be switched off and supported by the RS, while in the situation when all BS are active, i.e., 15th hour, and the CAP are all '1', no energy savings are feasible. To ascertain the energy saved by using the *BS-RS Switching* paradigm compared with putting the BS to sleep in each cell during the day, Fig. 4 and 5 plot the corresponding average percentage energy savings for the DL and UL respectively. For the former, an overall energy saving of up to 30% has been achieved in different cells depending on the traffic load variations in those cells, while up to 38% average energy saving is achieved for the MS. The additional energy consumed by the RS in the *BS-RS Switching* model is compensated for by maintaining the same propagation distance

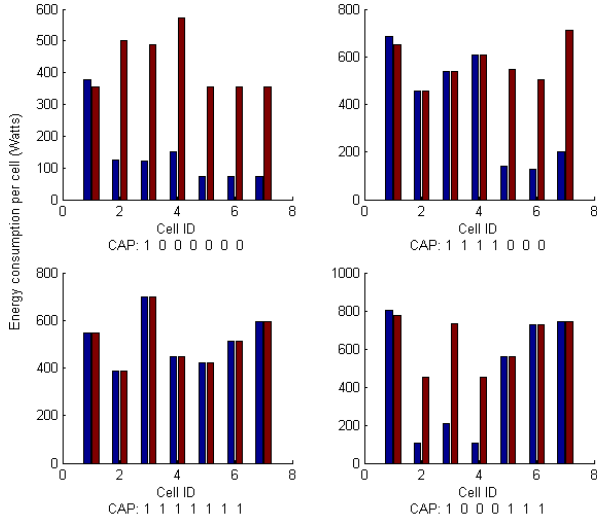


Fig. 3. Energy consumption snap shots in each cell during four (5th, 10th, 15th and 20th) hours of a day (blue bar - BS-RS Switching model, red bar - no switching).

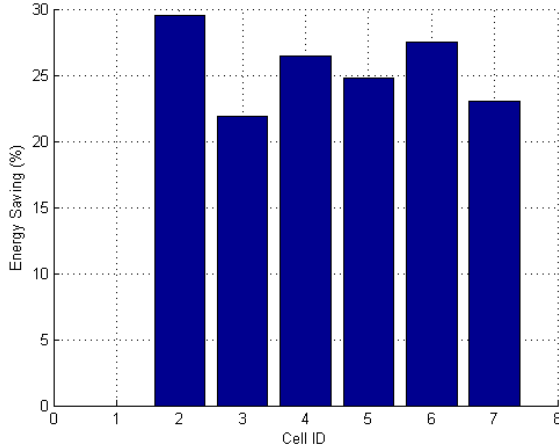


Fig. 4. Energy savings for the DL using the BS-RS Switching model compared to BS sleeping method [5] during a 24-hour period.

between the BS and MS, via the RS which requires lower transmit powers. In contrast, for the sleep mode technique, the propagation path-losses are higher because of the longer distances between the BS and off-cell MS, so the transmit powers are greater. Note, in both Fig. 4 and 5 there is no saving for the centre cell #1 because it is always active.

To ensure the minimum QoS provision is upheld, the average achievable DL data rate in each cell for the *BS-RS Switching* and BS sleep modes were analysed across an entire day, with the corresponding results displayed in Fig. 6. In this context, the maximum transmit power was considered, irrespective of the distance between BS and MS. Fig. 6 reveals the proposed *BS-RS Switching* mode improved the average data rate in each

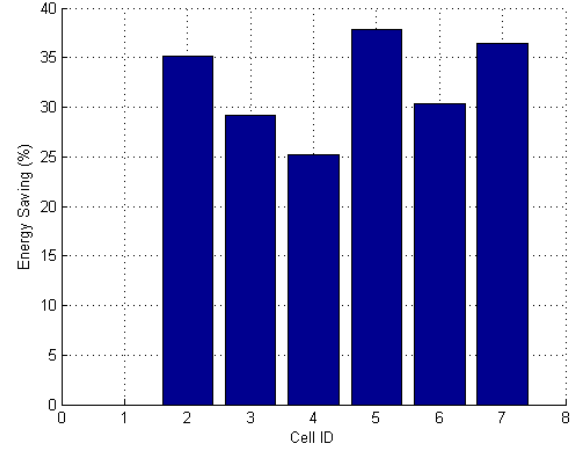


Fig. 5. Energy savings in the uplink for the BS-RS Switching compared to the BS sleeping method [5] over a 24-hour period.

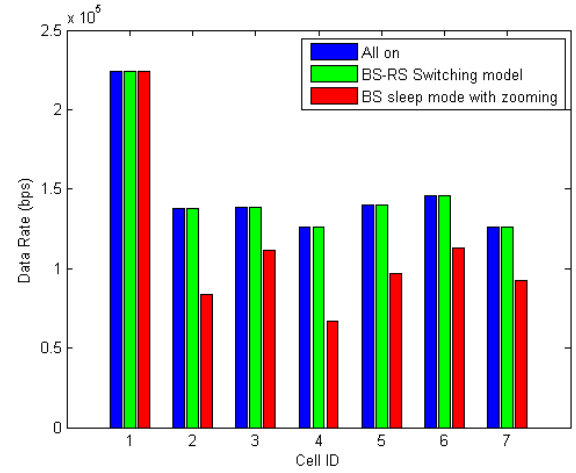


Fig. 6. Average DL data rate for the BS-RS Switching model compared to the BS sleeping method [5] over a 24-hour period.

cell, with the exception of centre cell #1, which is kept on all the time in both cases. The graph also confirms the data rates achieved with the new model are the same as those when all BS are active, so there is no compromising of the QoS in securing significantly lower energy consumption.

To evaluate the corresponding signal outage performance in the UL, the CDF of the respective received signal strengths are displayed in Fig. 7, where the signal outage probability threshold γ is defined in accordance with the LTE specification [15]. The results confirm that in the proposed *BS-RS Switching* model, no users will be in the outage region compared to nearly 15% when the BS sleep with cell zooming technique [5] is applied. Fig. 8 shows the EE performance for increasing cell loads for the *BS-RS Switching* and BS sleep approaches. In the former, the EE improved because all off-cell MS consume the same transmission power. This contrasts with the sleeping

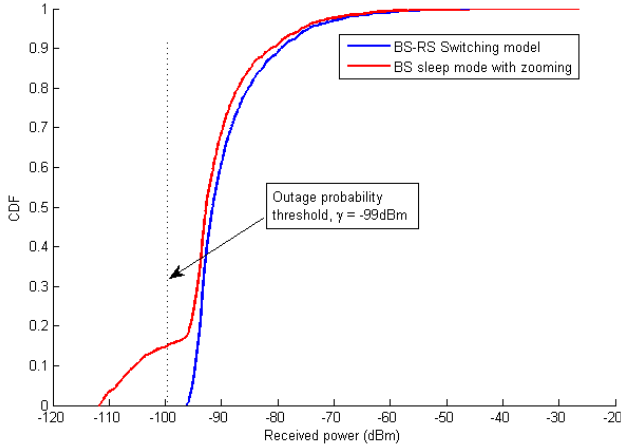


Fig. 7. Comparative CDF of the received power for a maximum MS transmit power of 21dBm.

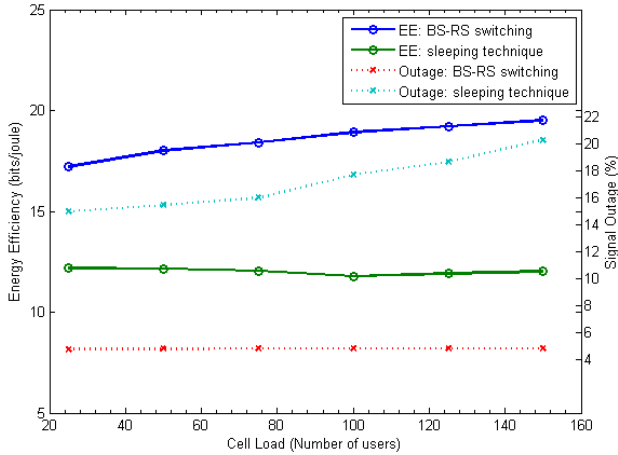


Fig. 8. Energy efficiency/Signal outage vs. cell load.

technique which has an approximately constant EE due to the increased power consumption of the off-cell MS offsetting any savings made by putting certain BS to sleep. This is also the reason for the correspondingly superior signal outage performance of the *BS-RS Switching* model, particularly at high cell loads. This vindicates the rationale of adopting the *BS-RS Switching* paradigm to achieve noteworthy improvements in EE while concomitantly maintaining the QoS provision.

IV. CONCLUSION

This paper has presented an energy efficient cellular network model, which switches from a *base station* (BS) to a *relay station* (RS) mode during *zero-to-medium* traffic periods. The rationale for the *BS-RS Switching* model is to guarantee uninterrupted communications between the mobile station and BS and thereby ensure the same *quality-of-service* (QoS) level as would be provided in normal BS mode. The simulation results

confirm the proposed *BS-RS Switching* model reduces energy consumption in both the up and downlinks while sustaining the requisite QoS. In the current simulation scenario, it has been assumed a RS is deployed at the same BS position and has the same coverage. Future work will focus on deploying more RS within a macrocell to keep the BS switched to RS mode for longer periods using dynamic switching, to secure further energy savings. The integration of cell zooming and load balancing strategies during peak macrocell periods will also be investigated.

REFERENCES

- [1] http://www.vodafone.com/content/index/about/sustainability/reporting_our_performance/data_file/eco-efficiency/co2_emissions_reporting.html, Accessed: 11-11-2011.
- [2] "Climate change: Commission welcomes final adoption of europe's climate and energy package," EC Press Release, Ref.- IP/08/2008, Dec. 2008, <http://europa.eu/rapid/pressReleasesAction.do?reference=IP/08/1998>, Accessed: 11-11-2011.
- [3] E. Oh and B. Krishnamachari, "Energy savings through dynamic base station switching in cellular wireless access networks," in *Global Telecommunications Conference (GLOBECOM 2010)*, 2010 IEEE, Dec. 2010, pp. 1-5.
- [4] F. Richter, A. Fehske, and G. Fettweis, "Energy efficiency aspects of base station deployment strategies for cellular networks," in *Vehicular Technology Conference Fall (VTC 2009-Fall)*, 2009 IEEE 70th, Sep. 2009, pp. 1-5.
- [5] Z. Niu, Y. Wu, J. Gong, and Z. Yang, "Cell zooming for cost-efficient green cellular networks," *Communications Magazine, IEEE*, vol. 48, no. 11, pp. 74-79, 2010.
- [6] X. Weng, D. Cao, and Z. Niu, "Energy-efficient cellular network planning under insufficient cell zooming," in *Vehicular Technology Conference (VTC Spring)*, 2011 IEEE 73rd. IEEE, 2011, pp. 1-5.
- [7] M. Marsan, L. Chiaraviglio, D. Ciullo, and M. Meo, "Switch-off transients in cellular access networks with sleep modes," in *Communications Workshops (ICC)*, 2011 IEEE International Conference on, Jun. 2011, pp. 1-6.
- [8] S. Elayoubi, L. Saker, and T. Chahed, "Optimal control for base station sleep mode in energy efficient radio access networks," in *INFOCOM, 2011 Proceedings IEEE*. IEEE, 2011, pp. 106-110.
- [9] M. Marsan, L. Chiaraviglio, D. Ciullo, and M. Meo, "Optimal energy savings in cellular access networks," in *Communications Workshops (ICC)*, 2009 IEEE International Conference on, Jun. 2009, pp. 1-5.
- [10] IEEE802.16j-06/013r3, "Multi-hop relay system evaluation methodology (channel model and performance metric)," IEEE 802.16 Broadband Wireless Access Working Group, Feb. 2007.
- [11] G. Boudreau, J. Panicker, N. Guo, R. Chang, N. Wang, and S. Vrzic, "Interference coordination and cancellation for 4g networks," *Communications Magazine, IEEE*, vol. 47, no. 4, pp. 74-81, 2009.
- [12] D. Lee, S. Zhou, and Z. Niu, "Multi-hop relay network for base station energy saving and its performance evaluation," in *Global Telecommunications Conference (GLOBECOM 2011)*, 2011 IEEE, Dec. 2011, pp. 1-5.
- [13] D. Cao, S. Zhou, C. Zhang, and Z. Niu, "Energy saving performance comparison of coordinated multi-point transmission and wireless relaying," in *Global Telecommunications Conference (GLOBECOM 2010)*, 2010 IEEE, Dec. 2010, pp. 1-5.
- [14] X. Ge, J. Hu, C. Wang, C. Youn, J. Zhang, and X. Yang, "Energy efficiency analysis of miso-ofdm communication systems considering power and capacity constraints," *Mobile Networks and Applications*, vol. 17, no. 1, pp. 29-35, 2012.
- [15] 3GPP, "Technical specification group radio access network; radio frequency system scenarios- 3gpp tr 25.942."
- [16] L. Saker, S. Elayoubi, and T. Chahed, "Minimizing energy consumption via sleep mode in green base station," in *Wireless Communications and Networking Conference (WCNC)*, 2010 IEEE. IEEE, 2010, pp. 1-6.